Potential for upscaling small scale irrigation (IDSS) – constraints and opportunities

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KEY QUESTIONS

- How much water/land is available for irrigation?
- How many farmers/households can it support?
- How sustainable is it?
  - Now into future
- What are the bottlenecks & opportunities?
  - Technologies, social/cultural, economics
- What are the optimum mixes of interventions?
- What difference will it make?
  - Income, health, and in the lives of people
- What changes in policy, practice and investments are necessary?
  - Local, regional, national
INTEGRATED DECISION SUPPORT SYSTEM (IDSS)

- **SWAT** – analyze the potentials and impacts of SSI at the watershed scale
- **APEX** – analyze cropping systems at the field scale, and
- **FARMSIM** – assess economic & nutritional impacts at household level
APPLICATIONS OF IDSS?

- Ex-ante analysis
  - Relied on existing data from literature and secondary sources
  - Useful to study impacts of SSI

- Ex-post analysis
  - Used field data to fine-tune the ex-ante analysis
  - Helped to understand more on the impacts of SSI
  - Vital for gaps and constraint analysis

- Gaps and constraints analysis to SSI
  - Critical to identify mitigation strategies for the gaps and constraints

- Upscaling analysis
  - Uses data and lessons learned from the ex-post analysis
  - Useful to understand the potentials and impacts of SSI at national level

- Capacity building
  - IDSS models, and other demand-driven tools
LAND SUITABILITY FOR IRRIGATION

- A large part of the watershed land use is either forest or bushland.
- Major rainfed crops were maize, and rice.
- Dry season irrigated crops were tomato and eggplant.
- Irrigation was implemented on ag. land, and part of the pasture land for tomato and fodder production (ca. ~2%).
- Streamflow was used for irrigation.
RESOURCES ASSESSMENT AT WATERSHED SCALE

- Average annual rainfall = 680 mm (260 million m³)
- Groundwater recharge (~30 million m³ over the watershed area of 387 km²)
- Surface runoff (~22 million m³ over the watershed)

- Amount of water required for dry season irrigation = 958,878 m³
  ~<1% of the streamflow leaving the watershed

- The streamflow diversion can support irrigation for vegetable and fodder production in a sustainable manner in the Kilosa watershed.
IMPACTS OF SSI AT THE WATERSHED SCALE

The bar chart shows the ratio of variables such as Streamflow/rainfall, ET/rainfall, Percolation/rainfall, Baseflow/total flow, and Surface runoff/total flow under Baseline condition and Ex-Ante Scenario.

The line graph represents the streamflow over years from 1985 to 2010, with peaks indicating significant events or changes.
Average tomato yield ranges b/n 10-20 ton/ha depending on the irrigation amount

Optimal water to maximize tomato yield is 550 mm/year

<table>
<thead>
<tr>
<th>Season total (mm)</th>
<th>Application rate (mm/2-day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1.54</td>
</tr>
<tr>
<td>250</td>
<td>3.85</td>
</tr>
<tr>
<td>400</td>
<td>6.15</td>
</tr>
<tr>
<td>550</td>
<td>8.46</td>
</tr>
<tr>
<td>700</td>
<td>10.77</td>
</tr>
<tr>
<td>850</td>
<td>13.08</td>
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</tbody>
</table>

**WATER USE FUNCTION OF TOMATO**

![Graph showing water use function of tomato](image)
WATER USE FUNCTION AND PUMPING TIME OF TOMATO

<table>
<thead>
<tr>
<th>Technology</th>
<th>Pumping capacity (l/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulley/bucket</td>
<td>10</td>
</tr>
<tr>
<td>Rope and washer pump</td>
<td>15</td>
</tr>
<tr>
<td>Motor pump</td>
<td>36</td>
</tr>
<tr>
<td>Solar pump</td>
<td>18</td>
</tr>
</tbody>
</table>

Over-irrigation:
- Costs more time and money
- A threat to irrigation expansion
Optimal fertilizer use is at 240 kg/ha Urea with 50 kg/ha DAP, Farmers’ practice is far lower and of different proportional rates.
## ECONOMIC AND NUTRITION IMPACTS

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Alt. 1 (MP-DI)</th>
<th>Alt. 2 (MP-FI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net present value</td>
<td>5,218,217</td>
<td>3,858,429</td>
<td>16,479,114</td>
</tr>
<tr>
<td>Avg. net profit</td>
<td>112,537</td>
<td>-860,005</td>
<td>931,536</td>
</tr>
<tr>
<td>% change profit: Alt./Baseline</td>
<td>-864%</td>
<td>728%</td>
<td></td>
</tr>
<tr>
<td>Benefit-Cost Ratio: Alt/Baseline</td>
<td>-0.6</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td><strong>Nutrition</strong></td>
<td>Min req.</td>
<td>Averages daily nutrients in year 5</td>
<td></td>
</tr>
<tr>
<td>Energy (calories/AE)</td>
<td>1750</td>
<td>3,780</td>
<td>3,785</td>
</tr>
<tr>
<td>Proteins (grs/AE)</td>
<td>41.2</td>
<td>77.0</td>
<td>77.3</td>
</tr>
<tr>
<td>Fat (grs/AE)</td>
<td>39</td>
<td>43.1</td>
<td>43.5</td>
</tr>
<tr>
<td>Calcium (grs/AE)</td>
<td>1</td>
<td>0.12</td>
<td>0.14</td>
</tr>
<tr>
<td>Iron (grs/AE)</td>
<td>0.009</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Vitamin A (grs/AE)</td>
<td>0.0006</td>
<td><strong>0.00028</strong></td>
<td>0.0009</td>
</tr>
</tbody>
</table>

**Note:**
- Baseline: No or minimal irrigation;
- Alt.1--MP-DI: Motor pump used with **Drip irrigation** in optimally irrigated systems
- Alt.2--MP-FI: Motor pump used with **Furrow irrigation** in optimally irrigated systems

**Observation:** the fusarium wilt disease caused major drop in yields in drip irrigation scenario which led to low production and income compared to furrow irrigation and baseline in Kilosa

AE = Adult Equivalent

For economic variables: numbers in green show increase while those in red show decrease

For nutrition variables: numbers in red show quantities of nutrients intake < minimum required
Probabilities of NCFI (profit) Less Than -860,000 and Greater Than 930,000 TZS in year 5
ILSSI field research showed SSI improves agricultural production, and household income & nutrition without compromising environmental sustainability. The main questions though are:

- What is the scale of investment for expanding SSI?
- Where are strategic investment potential areas? and
- What are the environmental and socio-economic impacts?

Upscaling instrumental to address these and other questions.
UPSCALING ANALYSIS FRAMEWORK

1. Land Cover (SPAM)
2. Soil
3. Climate
4. Terrain
5. Population density
6. Road network
7. HH survey

- **Suitability analysis**
  - Suitability domain with irrigation adoption possibility

- **Soil and Water Assessment Tool (SWAT)**
  - Crop yields, irrigation water demand & river basin water yields

- **Crop management practices**

- **Agent-based model (ABM) for irrigation expansion simulation**
  - Irrigation & production costs
  - National irrigation development potential

- **Econometric analysis**
SPATIALLY EXPLICIT ESTIMATION

- Spatial Production Allocation Model (SPAM) to disaggregate the land use data into different crop types for SWAT,
- SWAT to estimate spatially explicit water availability, water consumption, crop yields, and environmental impacts, and
- ABM to estimate economic-cost benefit and water balance.
AGENT-BASED MODEL (ABM) OUTPUT

- Adoption probability and area of SSI in each geographic domain across the country,
- Environmental risk of water scarcity due to the adoption,
- Economic benefit for irrigators from the adoption, and
- Number of beneficiary population.
322,000 km² land is suitable at 85% level of suitability

Overlay analysis

Rainfall deficit
Land use
Slope
Population
Road proximity
A large amount of water resources exists in the southeastern and central part of the country.
High potential for SSI is located in the central part of the country.
PROBABILITY OF IRRIGATION ADOPTION AND WATER SCARCITY

- a high adoption probability strip stretching from the border of Arusha/Kilimanjaro region to Mbeya region.

Potential area
754,454 ha

Profits
780 million USD/yr

Number of beneficiaries
3 million people
DEVELOPMENT OF DASHBOARD TO HARNESS THE POWER OF IDSS

- Alleviating end-users from being an expert in any specific models but to leverage from obtained results
- Planning and evaluation of SSI at multiple levels of scale
- Targeted end-users include:
  - Farmers and farmer organizations
  - Agents/practitioners that provide education and outreach
CAPACITY DEVELOPMENT FROM IDSS

- Regular workshops (5 days) – 120M + 42F
- Extended training for personnel from project countries (60-90 days)
- Graduate professional training in U.S. institutions (2-3 years)
- Continued support to stakeholders, graduate students, and CG systems (long term commitment)
- Institutionalization of IDSS (long term commitment)
IDSS TRAINING: DEMAND DRIVEN AND SOURCE OF INPUT TO ILSSI

- Based on user demand, the content of the training have been updated and additional workshop packages have been included, e.g.
  - IDSS-clinic,
  - Advanced SWAT Training, and
  - Interest to support UDES’s Regional MSc program at Department of Water Resources Engineering

- The workshops were important venue to exchange data and receive feedbacks on SSI practices in the project countries.
OVERALL OUTPUTS

- More than 50 reports and scientific articles produced - individual model per site, integrated site, and country reports, as well as scientific articles on the three ILSSI countries.

- Data for all the reports were shared to partners including through the Texas A&M University Library Dataverse. The data include:
  - Model outputs from SWAT, APEX and FARMSIM, which aid planning of SSI adoption,
  - Map for potential land suitability for SSI, and
  - Groundwater depth, Digital Elevation Model (DEM), high resolution soil and land use.

- Tools and models
  - SWAT/APEX/FarmSIM models, and QSWAT and Win-APEX interfaces
  - SSI Dashboard SSI for planning and evaluation at multiple levels of scale
  - Land suitability mapping tool, and
  - Weather data bias correction tool
OVERALL OUTCOMES

- IDSS – helpful tool to identify strategies to mitigate gaps and constraints of SSI
- SSI and application of optimal fertilizer rates increased agricultural production and economic outcome
- The source of the water, and the most profitable technology were site specific
  - Solar pumps – economical and workable
  - Labor – a major limitation on using low cost technology
- Minimal to modest environmental impacts due to adoption of SSI
- Substantial potential for scaling SSI nationally, e.g. more than 3 million people could be benefited and more than 780 million USD/year generated using SSI in Tanzania
- Key personnel trained with IDSS application, and IDSS institutionalized to educate the next generation scientists and professionals to scale up SSI
Note: Fusarium wild disease led to losses in tomatoes yields that caused the loss in profit for Alt. 1 scenario involving drip irrigation.
PLANNING AND EVALUATION OF SMALL SCALE IRRIGATION AT NATIONAL SCALE

Farms to Nations using models
IRRIGATION FOR DRY SEASON CROPPING (E.G. ONION)

- Only modest amount of irrigation needed to produce significant amount of vegetable and fodder during the dry season.